

5 **A REDUCED CARBON DIOXIDE EMISSION SYSTEM AND
METHOD FOR PROVIDING POWER FOR REFRIGERANT COMPRESSION AND
ELECTRICAL POWER FOR A LIGHT HYDROCARBON GAS LIQUEFACTION
PROCESS USING COOLED AIR INJECTION TO THE TURBINES**

RELATED CASES

10 [0001] This application is entitled to and hereby claims the benefit of the filing date of U.S.
Provisional Application No. 60/414,806 filed 09/30/02.

FIELD OF THE INVENTION

15 [0002] This invention relates to the production of liquefied light hydrocarbon gases by a
system and a process that produces a liquefied gas product more efficiently and with reduced
emissions of carbon dioxide (CO₂) to the atmosphere.

BACKGROUND OF THE INVENTION

20 [0003] In recent years, there has been continuing interest in liquefying natural gas and other
light hydrocarbon gases at remote sites where there is little or no nearby market for the
natural gas. Natural gas located at such remote sites is of market value only if it can be
pipelined or otherwise transported to a marketplace. In many instances, it is not feasible to
construct pipelines to transport such natural gas. Therefore, in many instances it has been
found desirable to liquefy the natural gas on site so that it can be transported by tanker to
markets.

25 [0004] A variety of processes for liquefying natural gas are known. In most of these
processes, the natural gas is treated to remove acid gases and otherwise treated to remove
water and hydrocarbons heavier than about C₃ as necessary prior to liquefaction. Known
natural gas refrigeration processes comprise processes that may use multiple pure component
refrigerants, multi-component refrigerants or combinations thereof. Refrigeration processes
30 using one or more refrigerant sections and the like may be used. A variety of such processes
are known and could be used with the present invention. All such processes generally require
that a compressed refrigerant be made available at a pressure such that upon cooling it can be

liquefied and thereafter vaporized to produce the refrigeration required to liquefy the natural gas.

[0005] Most such processes are quite energy intensive and require substantial energy input to compress the refrigerant for repeated cycling through a refrigeration zone to produce the refrigeration necessary to at least partially liquefy the natural gas and the like. Further, substantial energy may be required in many instances to recompress the natural gas after treatment to remove acid gases or water from the natural gas or to remove heavier hydrocarbons from the natural gas. All these processes typically require large quantities of electrical power and mechanical energy with the resultant emission of large quantities of carbon dioxide (CO₂) into the atmosphere.

[0006] Recently it has been considered that release of CO₂ into the atmosphere is detrimental to the atmosphere. Accordingly, it has been deemed desirable that the amount of CO₂ emitted in such processes should be reduced. Typically such processes have been operated in areas where there was an abundance of cheap fuel. Therefore, little concern has been directed to limiting the emission of CO₂ into the atmosphere since it was more convenient and economical to simply discharge combustion exhaust streams into the atmosphere than to limit the amount of fuel consumed since such fuel is readily available at little or no cost at the liquefaction site. As well known to those skilled in the art, hydrocarbon fuels, especially light hydrocarbon gases, have been used widely for generation of electrical power and for production of mechanical energy via light hydrocarbon gas fired turbines and the like.

[0007] Recently, it has become apparent that it would be desirable to provide a system and a process for providing compressed refrigerant and electrical power for a light hydrocarbon gas liquefaction process wherein reduced emissions of CO₂ were produced and wherein the mechanical energy and electrical power for the process could be produced on site.

[0008] In many instances, especially with aeroderivative turbines such as General Electric Company turbine models PGT16/LM1600, PGT25/LM2500, LM6000 and PGT225+/LM2500+HSPT, power losses as high as 15 percent can occur as a result of ambient air variations in temperature, humidity and the like. This large power loss dramatically reduces the quantity of light hydrocarbon gas that can be produced in a light hydrocarbon gas liquefaction process. Continued efforts have been directed to the development of systems and methods to avoid this power loss.

SUMMARY OF THE INVENTION

[0009] According to the present invention, a reduced carbon dioxide emissions method for providing power for refrigerant compression and shared electrical power for a light hydrocarbon gas liquefaction process comprises: a) cooling an air stream to a temperature below about 20°C to produce a cooled air stream; b) supplying at least a portion of the cooled inlet air stream to a plurality of light hydrocarbon gas-fired turbines; c) compressing a refrigerant in a plurality of compressors driven by the plurality of light hydrocarbon gas-fired turbines fueled by the cooled inlet air stream and a fuel gas stream with the turbines producing an exhaust stream at an elevated temperature; d) producing steam at an elevated temperature and pressure by heat exchange with the exhaust stream; e) driving a steam turbine with the steam from d) to produce mechanical power; and f) driving an electrical power generator with the mechanical power from e) to produce electrical power for use in the light hydrocarbon gas liquefaction process.

[0010] The invention further comprises a reduced carbon dioxide emissions system for providing power for refrigerant compression and shared electrical power for a light hydrocarbon gas liquefaction process, the system comprising: a) an air cooler having an air inlet and at least one cooled air outlet; b) a plurality of liquid hydrocarbon gas-fired turbines, each comprising an air compressor having a cooled air inlet in fluid communication with a cooled air outlet from the air cooler and a compressed air outlet in fluid communication with a combustion zone having a fuel inlet and a high-temperature, high-pressure combustion gas outlet in fluid communication with a combustion gas inlet to the turbine to drive the turbine, the turbine having a reduced pressure, high-temperature exhaust gas outlet; c) a refrigerant compressor driven by the turbine, having a low-pressure refrigerant inlet and an increased pressure refrigerant outlet with the refrigerant compressor being shaft coupled to a turbine; d) a heat exchanger having a water or low-pressure steam inlet and a steam outlet and a high-temperature, reduced pressure exhaust gas inlet in fluid communication with the reduced pressure, high-temperature exhaust gas outlet and a reduced pressure reduced temperature exhaust gas outlet so that the reduced pressure high-temperature exhaust gas passes in heat exchange relation with the water or low-pressure steam to produce steam and a reduced pressure, reduced temperature exhaust stream; e) a steam turbine in fluid communication

with the steam outlet of the heat exchanger; f) an electrical power generator which is shaft coupled to the steam turbine such that mechanical power produced by the steam turbine is used to drive the electrical power generator and produce electrical power; and g) a line in fluid communication with the increased pressure refrigerant outlet and the light hydrocarbon gas liquefaction process.

BRIEF DESCRIPTION OF THE FIGURE

[0011] In the discussion of the Figure, the same numbers will be used throughout to refer to the same or similar components. Further many pumps, valves, and other equipment known to those skilled in the art may be required to achieve the flow indicated but have not been shown for simplicity.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0012] In the Figure, turbines 10, 10', 10" and 10''' are shown positioned to supply mechanical power to drive refrigerant compressors 12, 12', 12" and 12"', employed to supply compressed refrigerant to a liquefaction process. The turbines are connected by shafts 14, 14', 14" and 14''' to refrigerant compressors 12, 12', 12" and 12"', which compressors may be axial, centrifugal, a combination of axial or centrifugal compressors, or the like. As shown, the turbines should be understood to include not only the turbine but also an axial compressor, centrifugal compressor or the like as required to supply compressed air (typically at a pressure from about 350 to about 800 psia) to the turbine. The turbines may also be shaft coupled to helper/starter electric motors which may be used to start or to start and drive the turbines. The turbines are powered by a hot combustion gas comprising high-pressure air introduced into the turbines by a line 22 and distribution lines 24. Line 22 should be understood to include valves, as necessary, to regulate flow into each of the turbines or to shut off flow to any or all of the turbines. The air in line 22 is supplied from a refrigeration unit 16 that cools an inlet air stream 18 to a desired temperature. Preferably the air is cooled to a temperature lower than about 20°C and preferably from about 8 to about 15°C and more preferably about 10°C. At this temperature water may be condensed from the air and it is shown as being discharged through a line 20. Cooling unit 16 may be propane cooler, a water/glycol system cooler or it may be any other type of suitable unit known to the

art for cooling air generally, such as a cooling unit that employs any environmentally acceptable coolant media. The unit may also cool the air using a coolant obtained from the liquefaction process for the liquefied gas if desired.

[0013] Desirably a natural gas or other light hydrocarbon gas stream is supplied as fuel for the turbines through a line 26 at a suitable pressure (about 350 to about 800 psia) for combination with the air in a combustion zone to produce a hot combustion gas at an elevated temperature and pressure (typically at a temperature from about 2800 to about 3000°F and a pressure from about 350 to about 800 psi) for use to drive the turbines. Line 28 should be considered to include valves, as necessary (not shown), to regulate the flow to any or all of the turbines. The turbines, when fueled and operated, drive refrigerant compressors 12, 12', 12" and 12''' to produce compressed refrigerant. The compressed refrigerant is typically produced from the refrigerant compressors (at a pressure from about 1 to about 75 bara) through lines 42 , 46, 98 and 100 respectively. The refrigerant compressed in individual refrigerant compressors may be compressed to different pressures in different quantities and may be a different refrigerant. These variations have not been shown in the Figure but are considered to be readily implemented if desired by those skilled in the art. The refrigerant may be passed to liquefaction plant facilities 54 at a single or at different points and at different pressures. As shown, gaseous spent refrigerant is recovered through a line 68 and passed back to the refrigerant compressors through lines 74, 80, 82 and 86 respectively. While four refrigerant compressors are shown, it is noted that fewer or more could be used.

[0014] The particular type of refrigeration process used is not considered to be part of the present invention. Compressed refrigerant is typically required in all natural gas liquefaction processes in large quantities. In most of these processes, the refrigerant may comprise multiple pure component refrigerants, multi-component refrigerants and combinations thereof. The processes may use a single liquefaction zone, multiple liquefaction zones or variations thereof. The particular process chosen is not considered to constitute a part of the present invention.

[0015] The recovered spent refrigerant is shown as passing back to the refrigerant compressors through a line 68 for distribution from lines 74, 80, 82 and 86 or to any or all of refrigerant compressors 12, 12', 12" and 12'''. It will be appreciated by those skilled in the art

that a variety of arrangements for handling the refrigerant are possible and obvious, dependent upon the type of refrigeration process practiced in the refrigeration zone or zones.

[0016] According to the present invention, improved efficiency is achieved in the compression of the refrigerant by use of the cooled inlet air to improve the efficiency in the compression section. The compression step increases the temperature of the inlet air and the temperature may impose an upper limit on the compression possible. Cooling the air prior to introducing the air into the air compression section of the turbines permits greater compression of the air thereby increasing the energy output of the turbine since the air is introduced at an initially lower temperature. Further the cooler permits the charging of the air at a near constant temperature. This air when combusted with the fuel produces a hot, high-pressure, high-temperature gas used to drive the turbines. The exhaust gases discharged from the turbines are high-temperature, low-pressure exhaust gases. The discharge of these gases is shown through line 30. The gases are passed through a heat exchanger section 32 where conventional heat exchange methods may be used to recover heat from the exhaust gas stream. The cooled exhaust gas stream (at a temperature below about 180°F) may then be discharged as desired through a line 33 to the atmosphere or the like. Low temperature steam or water is used as a heat exchange medium in heat exchanger 32 to produce high-pressure steam (typically at a pressure from about 400 to about 1200 psi) which is recovered through a line 34 and passed to an electrical generator 36. In the electrical generator 36 high-pressure steam is used to drive a turbine or the like to generate electrical power, which is placed on the grid for operation of the light hydrocarbon gas liquefaction process. The discharged stream recovered through line 38 is typically either water that has been previously treated for use to produce steam or low-temperature, low-pressure steam. Make up water may be added as desired through line a 40 with the mixture of water and steam and the like being recycled to heat exchanger 32.

[0017] By the process of the present invention, improved efficiency is accomplished by using cooler air at a controlled temperature as the inlet air to the turbine/air compressor system. This permits the compression of larger molecular quantities of air within the maximum temperature allowable for the air compressors. Both the air compressors and the refrigerant compressors are typically axial compressors, centrifugal compressors or the like as known to those skilled in the art.

[0018] By the practice of the present invention, not only is the efficiency of the turbines improved but also the generation of electrical power from the exhaust gases results in the production of electrical power, which is produced without the combustion of additional fossil fuel. As a result, CO₂ emissions from light hydrocarbon gas liquefaction processes as

disclosed are up to as much as sixty percent less than with similar processes wherein the exhaust gases from the turbine are simply exhausted without heat recovery and wherein electricity generated by the combustion of fossil fuels is used as the primary source of electricity for the operation of the liquefaction process. In accordance with the present invention, the reduction in CO₂ emissions may be up to 60 percent. Typically the reduction is at least about 35 percent, and is desirably from about 40 to about 60 percent.

[0019] The process operation has been described with the description of the system above. It is noted however that the most commonly liquefied light hydrocarbon gas is natural gas. It is also noted that, as well known to those skilled in the art, typically the natural gas is treated prior to liquefaction for the removal of at least a major portion of the acid gas compounds, removal of water as necessary and for the removal of C₃+ hydrocarbon gases. The removal of the heavier gases is desirable for a variety of reasons. First these gases may be of more value as products than as part of the liquefied natural gas stream. Further, these heavier hydrocarbon gases can cause problems by condensing in undesirable locations during the liquefaction process. Further the presence of such heavier hydrocarbons may increase the BTU value of the pipeline gas resulting from liquefaction of the natural gas beyond normal specifications. This can require the undesirable step of dilution with nitrogen or other inert gases.

[0020] As also noted previously the present invention is considered to be useful with substantially all natural gas liquefaction processes that require compressed refrigerant and electrical power. As shown in the Figure, LNG is recovered from facilities 54 via a line 70 and passed to LNG storage and export facilities 76. A boil-off gas stream 84 is passed from facilities 76 to facility 54. As noted above the turbines may be used to produce compressed refrigerant of the same or a different type. They also may be used to produce compressed refrigerants at different pressures and volumes. Further while four turbines are shown, it should be understood that more or fewer could be used.

5 [0021] A major advantage of the present invention is that air-cooling unit 16 is a stand-alone unit. This unit as shown is used to service four turbine and compressor systems. Additional systems could be serviced as well by a properly sized cooling unit. It is less economical to provide such a unit to supply cooled air to a single turbine or turbine/air compressor but it is economically advantageous to provide such a unit when it can be used to provide cooled air to a plurality of turbine units. As well known to those skilled in the art, when natural gas liquefaction processes are expanded they are typically expanded as units. In other words, additional liquefaction zones are added with additional compressors and turbines to increase the capacity of the overall process. With proper sizing, air-cooling unit 16 can provide cooled air to a large number of turbine/air compressor units. This results in substantially increased efficiency in each of the units and the operation of air cooler 16 is a relatively minor expense when distributed over the operation of the large number of turbines. The larger the number of turbines serviced by air cooler 16, the greater the economic benefits from using a single air cooler to provide the cooled air to all the units.

10 [0022] By further combining this process with the recovery of electrical power from the hot exhaust gas, greatly improved efficiency in the overall process is achieved.

15 [0023] While the present invention has been described by reference to certain of its preferred embodiments, it is pointed out that the embodiments described are illustrative rather than limiting in nature and that many variations and modifications are possible within the scope of the present invention. Many such variations and modifications may be considered obvious and desirable by those skilled in the art based upon a review of the foregoing description of preferred embodiments.